

## DESCRIPTION

## HLA-DR-BINDING ANTIGEN PEPTIDE DERIVED FROM WT1

## 5 TECHNICAL FIELD

The present invention relates to HLA-DRB1\*0405-binding antigen peptides derived from WT1.

## BACKGROUND ART

WT1 gene (Wilms' tumor gene 1) has been identified as one of causative genes of Wilms' tumor that is a childhood renal tumor (*Cell* 60: 509, 1990, *Nature* 343: 774, 1990). WT1 gene encodes the transcription factor WT1 which plays an important role in many processes such as proliferation, differentiation and apoptosis of cells, and development of tissues (*Int. Rev. Cytol.* 181: 151, 1998). WT1 gene was originally defined as a tumor suppressor gene. However, subsequent studies revealed that WT1 gene is highly expressed in leukemia and various solid cancers including lung cancer and breast cancer, indicating that WT1 gene rather exerts an oncogenic function that promotes cancer growth. In addition, it was demonstrated that, when peripheral blood mononuclear cells positive for HLA-A\*0201 or HLA-A\*2402 were stimulated *in vitro* with WT1-derived peptides, peptide-specific cytotoxic T-lymphocytes (CTLs) were induced and killed leukemic or solid tumor cells which endogenously express WT1. These results demonstrated that WT1 is a promising target molecule of cancer immunotherapy (*Int. J. Hematol* 76: 127, 2002).

It has been reported that presence of helper T cells specific to cancer antigen is essential for effective induction of CTLs (*Cancer. Res.* 62: 6438, 2002).

Helper T cells (CD4-positive T cells) are induced (made proliferate) and activated when they recognize a complex of MHC class II molecule and

antigen peptide on antigen-presenting cells. The activated helper T cells produce cytokines such as IL-2, IL-4, IL-5, IL-6, and/or interferons and mediate the growth, differentiation, and maturation of B cells. The activated helper T cells also function to promote the growth, differentiation or maturation of other subsets of T cells such as Tc and TD cells. Thus, the activated helper T cells can activate the immune system through the promotion of growth and activation of B and T cells. Therefore, it was suggested to be helpful to enhance functions of helper T cells being under the influence of MHC-class II-binding antigen peptide (also referred to as "helper peptide"), whereby efficacy (potency) of cancer vaccine in cancer immunotherapy (cancer vaccine therapy) is increased (*J. Immunother.*, 24:195, 2001).

As for WT1-derived peptides, only one antigen peptide is known to bind to a subtype of MHC class II molecule, i.e., HLA-DRB1\*0401 (*Cancer Immunol. Immunother.* 51:271, 2002). There are no WT1-derived peptides which have been reported to bind to different subtypes.

#### DISCLOSURE OF INVENTION

The purpose of the present invention is to provide HLA-DRB1\*0405-binding antigen peptides derived from WT1, and use of the peptide as an enhancer of cancer vaccine efficacy (an agent for enhancing efficacy of cancer vaccine).

The present inventor has conducted intensive study on WT1-derived antigen peptides ("helper peptides") having an activity of binding to MHC class II antigen and enhancing the cancer vaccine efficacy (potency) in cancer immunotherapy. In consequence, the present inventor has for the first time found that WT1 contains an antigen peptide portion(s) which has an activity of binding to HLA-DRB1\*0405 among a number of MHC class II subclasses and inducing helper T cells. This finding led to the development of a novel therapeutic method by which WT1-specific helper T

cells are induced and enhanced in HLA-DRB1\*0405-positive cancer patients.

Recent researches revealed that there exists promiscuous helper peptides which are helper peptides capable of binding to plural HLA-class II molecules and inducing helper CD4-positive T cells (*British J. cancer*, 85(10), p1527-1534 (2001); *J. Immunol.*, 169, p557-565 (2002)). The present inventor made investigation into WT1<sub>332-347</sub>, which is one of the above-described HLA-DRB1\*0405-binding antigen peptides (helper peptides), to elucidate whether or not it is potentially a promiscuous helper peptide. As a result, said peptide proved to be a promiscuous helper peptide that binds not only to HLA-DRB1\*0405 molecule but also to HLA-DRB1\*1502. Thus, the WT1<sub>332-347</sub> peptide of the present invention is a helper peptide applicable to patients having HLA-DRB1\*1502 as well as those having HLA-DRB1\*0405. The present inventor also found that WT1 contains an antigen peptide portion(s) capable of binding to HLA-DRB1\*1502, one of a number of MHC class II subclasses, and inducing helper T cells for the first time.

The present invention has been established on the basis of these findings.

The present invention encompasses the followings.

(1) A peptide consisting of 10 - 25 contiguous amino acids in the amino acid sequence of human WT1 shown in SEQ ID NO: 1, which binds to HLA-DRB1\*0405 and induces helper T cells.

(2) The peptide of (1) above, which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23.

(3) The peptide of (2) above, which comprises the amino acid sequence set forth in SEQ ID NO: 24.

(4) A peptide of 10 - 25 amino acids, which comprises an amino acid sequence wherein the amino acid residue at position 1, 4, 6 and/or 9 of an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23 is

substituted by another amino acid residue, and which binds to an HLA-DRB1\*0405 and induces helper T cells.

(5) The peptide of (4) above, which comprises an amino acid sequence wherein the amino acid residue at position 1, 4, 6 and/or 9 of an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23 is substituted by an amino acid residue selected from the following amino acids:

phenylalanine, tyrosine, tryptophan, valine, isoleucine, leucine and methionine for the position 1;

valine, isoleucine, leucine, methionine, aspartic acid and glutamic acid for the position 4;

asparagine, serine, threonine, glutamine, lysine and aspartic acid for the position 6; and

aspartic acid, glutamic acid and glutamine for the position 9.

(6) The peptide of (5) above, which comprises an amino acid sequence wherein the amino acid residue at position 3, 6, 8 and/or 11 of the amino acid sequence set forth in SEQ ID NO: 24 is substituted by an amino acid residue selected from the following amino acids:

phenylalanine, tryptophan, valine, isoleucine, leucine and methionine for the position 3;

valine, isoleucine, methionine, aspartic acid and glutamic acid for the position 6;

asparagine, serine, threonine, glutamine, lysine and aspartic acid for the position 8; and

aspartic acid, glutamic acid and glutamine for the position 11.

(7) A peptide consisting of 10 - 25 contiguous amino acids in the amino acid sequence of human WT1 shown in SEQ ID NO: 1, which binds to HLA-DRB1\*1502 and induces helper T cells.

(8) The peptide of (7) above, which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 46 - 56.

(9) The peptide of (7) above, which comprises the amino acid sequence set forth in SEQ ID NO: 24.

(10) A peptide comprising a peptide described in any one of (1) to (9) above together with a cancer antigen peptide.

5 (11) A polynucleotide encoding a peptide described in any one of (1) to (10) above.

(12) An expression vector containing the polynucleotide described in (11) above.

(13) A cell containing the expression vector described in (12) above.

10 (14) A process for producing a peptide described in any one of (1) to (10) above, which comprises culturing the cell described in (13) above under the condition where the peptide can be expressed.

(15) An antibody which specifically binds to a peptide described in any one of (1) to (9) above.

15 (16) A pharmaceutical composition which comprises a peptide described in any one of (1) to (10) above, an expression vector described in (12) above or a cell described in (13) above, in association with a pharmaceutically acceptable carrier.

20 (17) The pharmaceutical composition of (16) above, which is a therapeutic or preventive agent for cancer.

25 (18) The pharmaceutical composition of (16) above, which is an inducer of helper T cells, and which comprises a peptide described in any one of (1) to (9) above; an expression vector described in (12) related to a peptide of any one of (1) to (9) above; or a cell described in (13) above related to a peptide of any one of (1) to (9) above, in association with a pharmaceutically acceptable carrier.

30 (19) The pharmaceutical composition of (16) above, which is an enhancer of cancer vaccine efficacy, and which comprises a peptide described in any one of (1) to (9) above; an expression vector described in (12) related to a peptide of any one of (1) to (9) above; or a cell described in

(13) above related to a peptide of any one of (1) to (9) above, in association with a pharmaceutically acceptable carrier.

(20) The pharmaceutical composition of (16) above, which is a therapeutic or preventive agent for cancer, and which comprises a peptide described in (10) above; an expression vector described in (12) related to a peptide of (10) above; or a cell described in (13) above related to a peptide of (10) above, in association with a pharmaceutically acceptable carrier.

(21) Use of a peptide described in any one of (1) to (10) above, an expression vector described in (12) above or a cell described in (13) above for the manufacture of a therapeutic or preventive agent for cancer.

(22) A method of treating or preventing cancer, which comprises administering a peptide described in any one of (1) to (10) above, an expression vector described in (12) above or a cell described in (13) above to a subject in need thereof.

(23) A pharmaceutical composition which comprises a peptide described in any one of (1) to (9) above in combination with a cancer antigen peptide.

(24) The pharmaceutical composition of (23) above, which is used for treating or preventing cancer.

(25) A kit for treating or preventing cancer, which comprises a pharmaceutical composition comprising a peptide of any one of (1) to (9) above in association with a pharmaceutically acceptable carrier, and a pharmaceutical composition comprising a cancer antigen peptide in association with a pharmaceutically acceptable carrier.

(26) Use of a peptide of any one of (1) to (9) above in combination with a cancer antigen peptide in the manufacture of a therapeutic or preventive agent for cancer.

(27) A method of treating or preventing cancer, which comprises administering a peptide of any one of (1) to (9) above in combination with a cancer antigen peptide to a subject in need thereof.

The present invention provides an HLA-DRB1\*0405-binding antigen peptide derived from WT1, a polynucleotide encoding the peptide, an inducer of helper T cells ("helper T cell inducer") comprising said peptide or polynucleotide, and the like. The helper T cell inducer of the present invention is useful as an enhancer of cancer vaccine efficacy. The enhancer of cancer vaccine efficacy of the present invention is applicable to many HLA-DRB1\*0405-positive patients, and is particularly useful for enhancing efficacy of WT1 vaccine.

## 10 BRIEF DESCRIPTION OF DRAWINGS

Figure 1 shows the results of examination into responsiveness of CD4-positive T cells (helper T cells) stimulated with a WT1-derived WT<sub>1332-347</sub> peptide to various dendritic cells. In the figure, "Untreated" represents the responsiveness to dendritic cells not pulsed with a peptide; "PHA" the results of examination wherein CD4 positive T cells were treated with PHA instead of dendritic cells, "WT<sub>1172-186</sub> pulse" the responsiveness to dendritic cells pulsed with WT<sub>1172-186</sub> peptide, "WT<sub>1225-243</sub> pulse" the responsiveness to dendritic cells pulsed with WT<sub>1225-243</sub> peptide, and "WT<sub>1332-347</sub> pulse" the responsiveness to dendritic cells pulsed with "WT<sub>1332-347</sub> peptide. The vertical axis indicates the amount of [<sup>3</sup>H]-thymidine uptake (cpm) by CD4-positive T cells.

Figure 2 shows the results of examination into responsiveness of G2 cell lines to dendritic cells pulsed with a WT1-derived WT<sub>1332-347</sub> peptide. In the figure, "Untreated" represents the results obtained using dendritic cells not pulsed with a peptide; and "WT<sub>1332-347</sub> pulse" to the results obtained using dendritic cells pulsed with WT<sub>1332-347</sub>. The vertical axis indicates the amount of [<sup>3</sup>H]-thymidine uptake (cpm) by G2 cell lines.

Figure 3 shows the results of examination into responsiveness of G2 cell line to B-LCL(+) cells expressing WT1 gene. In the figure, "B-LCL(-)" represents the results obtained using B-LCL(-) cells not-expressing WT1

gene, "B-LCL(+) the results obtained using B-LCL(+) cells expressing WT1 gene, and "B-LCL(+) + anti-HLA-DR antibody" to the results obtained using B-LCL(+) cells treated with anti-HLA-DR antibody. The vertical axis indicates the amount of [<sup>3</sup> H]-thymidine uptake (cpm) by G2 cell lines.

Figure 4 shows the results of examination into responsiveness of E04.1 cell line to dendritic cells pulsed with a WT1-derived WT<sub>1332-347</sub> peptide. In the figure, "-" represents the results obtained using dendritic cells not pulsed with a peptide, and "332" the results obtained using dendritic cells pulsed with WT<sub>1332-347</sub> peptide. The vertical axis indicates the amount of [<sup>3</sup> H]-thymidine uptake (cpm) by E04.1 cell lines.

Figure 5 shows the results of examination into responsiveness of E04.1 cell line to stimulated cells which have been pulsed with WT1-derived WT<sub>1332-347</sub> peptide and then treated with various anti-HLA inhibitory antibodies. The stimulated cell used is B-LCL(-) cell which is a B cell line established from blood of a healthy volunteer positive for HLA-DRB1\*0405 as shown herein below in Example 3. In the figure, "-" represents the results obtained using stimulated cells not pulsed with a peptide, and "332" the results obtained using stimulated cells pulsed with WT<sub>1332-347</sub> peptide. Further, "332+ $\alpha$ -classI" represents the results obtained using stimulated cells treated with WT<sub>1332-347</sub> peptide and anti-HLA-class I antibody, "332+ $\alpha$ -DR" to the results obtained using stimulated cells treated with the WT<sub>1332-347</sub> peptide and anti-HLA-DR antibody, "332+ $\alpha$ -DQ" to the results obtained using stimulated cells treated with WT<sub>1332-347</sub> peptide and anti-HLA-DQ antibody. In addition, "332+mIgG" represents the results obtained using stimulated cells treated with WT<sub>1332-347</sub> peptide and anti-mouse-IgG antibody as a negative control for inhibitory antibody. The vertical axis indicates the amount of [<sup>3</sup> H]-thymidine uptake (cpm) by E04.1 cell lines.

Figure 6 shows the results of examination into responsiveness of E04.1 cell line to HLA-DRB1\*0405-positive or -negative PBMC pulsed with

WT1-derived WT1<sub>332-347</sub> peptide. In the figure, "-" represents the results obtained using PBMC not pulsed with a peptide, and "332" the results obtained using PBMC pulsed with WT1<sub>332-347</sub> peptide. HLA-DRB1 genotypes of respective donors are as follows. Donor 1 (HLA-DRB1\*0405/0803), Donor 2 (HLA-DRB1\*0405/0101), Donor3 (HLA-DRB1\*0101/1001) and Donor 4 (HLA-DRB1\*1201/0802). The vertical axis indicates the amount of [<sup>3</sup> H]-thymidine uptake (cpm) by E04.1 cell lines.

Figure 7 shows the results of examination into responsiveness of E04.1 cell line to B-LCL(+) cells expressing WT1 gene. In the figure, "B-LCL(-)" represents the results obtained using B-LCL(-) cell not-expressing WT1 gene as stimulated cells, and "B-LCL(+)" the results obtained using B-LCL(+) cells expressing WT1 gene as stimulated cells. The vertical axis indicates the amount of [<sup>3</sup> H]-thymidine uptake (cpm) by E04.1 cell lines.

Figure 8 shows the results of examination into responsiveness of E04.1 cell line to dendritic cells pulsed with B-LCL(+) cells in which apoptosis has been induced. In the figure, "apoptotic B-LCL (+)" represents the results obtained using dendritic cells pulsed with B-LCL(+) cells expressing WT1 gene and having been induced apoptosis, and "apoptotic B-LCL (-)" represents the results obtained using dendritic cells pulsed with B-LCL(-) cells not-expressing WT1 gene and having been induced apoptosis. Further, "E04.1+" represents the results obtained by cocultivation of E04.1 cells with dendritic cells, and "E04.1-" the results obtained by cocultivation without E04.1 cells. The vertical axis indicates the amount of [<sup>3</sup> H]-thymidine uptake (cpm) by E04.1 cell lines.

Figure 9 shows the results of examination into cytokine production of E04.1 cell lines to dendritic cells pulsed with WT1-derived WT1<sub>332-347</sub> peptide. In the figure, "-" represents the results obtained using dendritic cells not pulsed with a peptide, and "332" the results obtained using dendritic cells pulsed with WT1<sub>332-347</sub> peptide. The vertical axis indicates the percentage (%) of E04.1 cells showing the production of IL-4 (blank bar)

or IFN- $\gamma$  (filled bar).

Figure 10 shows the results of analysis of E04.1 cell line stained with anti-CD4 antibody and anti-CXCR3 antibody by flow cytometer. In the figure, the horizontal and vertical axes indicate cells positive for CD4 and for CXCR3, respectively. The percentage of cells positive for both CD4 and CXCR3 was 90.1%.

Figure 11 shows the results of examination into influence of WT1-derived WT1<sub>332-347</sub> peptide on the induction of WT1-specific CTLs. PBMCs originated in a healthy volunteer (HLA-A\*2402/1101, DRB1\*0405/0803) were cultured for 7 days under the stimulation conditions of (A) WT1<sub>235-243</sub> peptide, (B) WT1<sub>235-243</sub> peptide + WT1<sub>332-347</sub> peptide, (C) WT1<sub>235-243</sub> peptide + E04.1 cell and (D) WT1<sub>235-243</sub> peptide + WT1<sub>332-347</sub> peptide + E04.1 cell. Then, one half of the recovered cells were analyzed with flow cytometer to obtain the percentage of WT1<sub>235-243</sub>-specific CTL precursors. The horizontal and vertical axes indicate the percentage of cells positive for CD8 and for WT1<sub>235-243</sub> peptide/HLA-A\*2402, respectively.

Figure 12 shows the results of examination into influence of WT1-derived WT1<sub>332-347</sub> peptide on the activation of WT1-specific CTLs. Another half of the cells recovered in the experiment mentioned in Figure 11 were stimulated with WT1<sub>235-243</sub> peptide for 6 hours, and intracellular IFN- $\gamma$  was stained. The vertical and horizontal axes indicate the cells positive for intracellular IFN- $\gamma$  and for anti-mouse IgG antibody, respectively. The figure shows the results of stimulation with (E) WT1<sub>235-243</sub> peptide, (F) WT1<sub>235-243</sub> peptide + WT1<sub>332-347</sub> peptide, (G) WT1<sub>235-243</sub> peptide + E04.1 cell, (H) WT1<sub>235-243</sub> peptide + WT1<sub>332-347</sub> peptide + E04.1 cell.

Figure 13 shows the results of examination into responsiveness of CD4-positive T cells stimulated with WT1-derived WT1<sub>332-347</sub> peptide with various dendritic cells. In the figure, "-" represents the responsiveness with dendritic cells not pulsed with a peptide, "332" the responsiveness with dendritic cells pulsed with WT1<sub>332-347</sub> peptide, "172" the

responsiveness with dendritic cells pulsed with WT1<sub>172-186</sub> peptide, and "225" the responsiveness with dendritic cells pulsed with WT1<sub>225-243</sub> peptide. The vertical axis indicates the amount of [<sup>3</sup>H]-thymidine uptake (cpm) by CD4-positive T cells. The symbol "##" and "n.s." mean that the difference in the test groups is statistically significant or is not, respectively.

Figure 14 shows the results of T-cell repertoire analysis of CD4-positive T cells stimulated with WT1-derived WT1<sub>332-347</sub> peptide. The cells were stained with different antibodies specific for respective V $\beta$  chains of TCR and analyzed by flow cytometry. In the upper panel, the cell population in the lower right portion of quartered area represents V $\beta$  3-positive cells. In the lower panel, the cell population in the lower right portion of quartered area represents V $\beta$  20-positive cells.

Figure 15 shows the results of examination into the responsiveness of E15.1 cell line or E15.2 cell line to autologous PBMCs pulsed with WT1-derived WT1<sub>332-347</sub> peptide. In the figure, "-" represents the results obtained by using autologous PBMCs not pulsed with a peptide, and "332" the results obtained using autologous PBMCs pulsed with WT1<sub>332-347</sub> peptide. The vertical axis indicates the amount of [<sup>3</sup>H]-thymidine uptake (cpm) by separated cell lines. A) and B) show the results obtained using E15.1 cell line and E15.2 cell line, respectively. The symbol "##" means that the difference in the test groups is statistically significant.

Figure 16 shows the results of examination into cytokine production of E15.2 cell line to autologous PBMCs pulsed with WT1-derived WT1<sub>332-347</sub> peptide. In the figure, "-" represents the results obtained using dendritic cells not pulsed with a peptide, and "332" the results obtained using autologous PBMCs pulsed with WT1<sub>332-347</sub> peptide. The vertical axis indicates the percentage (%) of E15.2 cells showing the production of IL-4 (blank bar) or IFN- $\gamma$  (filled bar).

Figure 17 shows the results of examination into the relation between the concentration of WT1-derived WT1<sub>332-347</sub> peptide pulsed into autologous

PBMCs and the responsiveness of E15.2 cell line. The vertical axis indicates the amount of [<sup>3</sup>H]-thymidine uptake (cpm) by E15.1 cell lines. The horizontal axis indicates the concentration of WT<sub>1332-347</sub> peptide pulsed into autologous PBMC.

Figure 18 shows the results of examination into responsiveness of E15.2 cell line to PBMCs positive or negative for HLA-DRB1\*1502 pulsed with WT1-derived WT<sub>1332-347</sub> peptide. In the figure, “-” represents the results obtained by using PBMCs not pulsed with the WT<sub>1332-347</sub> peptide, and “332” the results obtained using PBMCs pulsed with the peptide. A) shows the results obtained using PBMCs from an HLA-DRB1\*1502-positive healthy volunteer and B) the results obtained using PBMCs from an HLA-DRB1\*1502-negative healthy volunteer. The vertical axis indicates the amount of [<sup>3</sup>H]-thymidine uptake (cpm) by E15.2 cell lines. The symbol “\*\*\*” and “n.s.” mean that the difference in the test groups is statistically significant or not, respectively.

#### BEST MODE FOR CARRYING OUT THE INVENTION

The present invention provides a peptide consisting of 10 - 25 contiguous amino acids in the amino acid sequence of human WT1 set forth in SEQ ID NO: 1, said peptide binding to HLA-DRB1\*0405 and inducing helper T cells. The present invention encompasses peptides wherein the N-terminal and/or C-terminal amino acid residue is modified or those wherein a particular amino acid residue(s) is altered.

Hereinafter, “a peptide that induces helper T cells (or a peptide that induces CD4-positive T cells)” may be referred to as “a helper peptide”.

The amino acid sequence of human WT1 set forth in SEQ ID NO: 1 is a known sequence as described in *Cell*, **60**:509, 1990, and NCBI data base (Accession Nos. XP\_034418 and P19544).

The peptide of the present invention is a partial peptide which consists of 10 - 25 contiguous amino acids present in the amino acid

sequence of human WT1 set forth in SEQ ID NO: 1. The definition of "10 - 25 amino acids" is based on the facts that peptides having an activity of binding to MHC class II generally consist of 10 to 25 amino acids (*Immunogenetics*, 41: 178-228, 1995, *Biochimica et Biophysica Acta* 1316, 5 85-101 (1996), *Immunology*, 96, 1-9 (1999), *Peptides*, Vol. 19, 179-198 (1998), *Immunobiology*, 5th Edt., 116-117, Garland Publishing (2001)). Preferred peptides are those consisting of 13 - 17 contiguous amino acids in the amino acid sequence of human WT1.

The peptide of the present invention can be identified by 10 synthesizing a peptide (candidate peptide) consisting of 10 - 25 contiguous amino acids in the amino acid sequence set forth in SEQ ID NO: 1, and assaying whether or not the peptide is capable of binding to HLA-DRB1\*0405 and inducing helper T cells.

The synthesis of a peptide can be conducted according to processes 15 generally used in the field of peptide chemistry. Such a method can be found in literatures including *Peptide Synthesis*, Interscience, New York, 1966; *The Proteins*, Vol. 2, Academic Press Inc., New York, 1976; *Peptide Synthesis*, Maruzen, Inc., 1975; *Peptide-Gosei no Kiso to Jikken*, Maruzen, Inc., 1985; and *Iyakuhin no Kaihatsu (Zoku)*, Vol. 14, Peptide Synthesis, 20 Hirokawa-syoten, 1991.

It can be examined whether or not a candidate peptide binds to HLA-DRB1\*0405 and induces helper T cells using a method described in, for example, *Cancer. Immunol. Immunother.* 51: 271 (2002), the method described in the working Examples, or the method described just below.

25 Specifically, dendritic cells (adherent cells) are prepared by isolating peripheral blood mononuclear cells (PBMCs) from a human subject positive for HLA-DRB1\*0405, and removing non-adherent cells. Separately, helper T cells (CD4-positive T cells) are prepared from the same HLA-DRB1\*0405-positive subject by density gradient centrifugation with Ficoll-Paque, and 30 so on.

The above-described dendritic cells are cultured after addition of a candidate peptide, and further cultured with the above-described helper T cells. The helper T cells are then recovered and stimulated several times with dendritic cells pulsed with the candidate peptide in a similar manner.

5 It is possible to evaluate whether or not helper T cells are induced (activated) in response to stimulation with a peptide by measuring, for example, (1) growth activity of helper T cells or (2) cytokine-producing-activity of helper T cells. Specifically, the growth activity (1) can be examined by measuring the amount of [<sup>3</sup>H]-thymidine uptake by helper T cells. The cytokine-producing activity (2) can be examined by measuring the amount of cytokine such as IFN- $\gamma$  produced by activated helper T cells by enzyme enzyme-linked immunosorbent assay (ELISA) or the like.

10 The amino acid sequence of antigen peptides binding to MHC class I or MHC class II molecule and being presented obeys a certain rule (binding motif). There are terminal amino acid residues at the both ends of peptides binding to MHC class I molecule which play a significant role in the binding with MHC class I molecule; however, there are no such amino acids at either end of peptides binding to MHC class II molecule, and the terminal amino acids do not bind to MHC class II molecule. Such a peptide rather is accommodated and immobilized (fixed) in a peptide-binding groove longitudinally. The immobilization of a peptide in a peptide-binding groove can be achieved through the binding of the side chains of amino acids constituting the peptide to the peptide-binding groove and the binding of the main chain of the peptide to the side chains 15 of amino acids well-preserved in the entire peptide-binding groove for MHC class II molecules. A peptide-binding groove has small or large pockets and there is amino acid polymorphism in the amino acid residues constituting the pockets depending on the MHC class II molecule.

20 X-ray crystallography obtained so far revealed that side chains of amino acid residues at positions 1, 4, 6 and 9 of the smallest MHC class II-

binding peptide engage with these binding pockets.

The amino acid motif of peptides binding to a pocket(s) of peptide-binding groove can be estimated by analyzing the pattern of amino acid residues commonly found in the binding peptides for respective MHC class II molecules originated in different alleles. It is considered that, because peptides of about 9 amino acids having such a motif is accommodated in the peptide-binding groove in such a manner that the both termini protrude from the both sites of groove, there are basically no limitations regarding the length of peptides which can bind to MHC class II molecules. However, in many cases, a long peptide is cleaved into peptides of 13-17 amino acid length by peptidases (*Immunobiology*, 5th Edt., 116-117, Garland Publishing (2001)).

Regarding the peptide which has the binding activity for HLA-DRB1\*0405, the amino acids at positions 1,4, 6 and 9 in the HLA(MHC)-binding domain consisting of 9-amino acids are expected to have the following regularities (motifs) (*Immunogenetics*, 41,178-228(1995), *Biochimica et Biophysica Acta* 1316, 85-101 (1996)).

Position 1: phenylalanine (F), tyrosine(Y), tryptophan(W), valine(V), isoleucine(I), leucine(L) and methionine(M)

Position 4: valine(V), isoleucine(I), leucine (L), methionine(M), aspartic acid(D) and glutamic acid(E)

Position 6: asparagine(N), serine(S), threonine(T), glutamine(Q), lysine(K) and aspartic acid(D)

Position 9: aspartic acid(D), glutamic acid(E) and glutamine(Q)

Recently, it has become possible to search for peptide sequences expected to bind to MHC class II antigen using software for predicting MHC class II binding peptides (Propred, *Bioinformatics* 17: 1236, 2001).

The present invention is based on the finding that WT1 (SEQ ID NO: 1) contains antigen peptide portions which bind to HLA-DRB1\*0405 (a kind of MHC class II) and induce helper T cells for the first time. Examples

of putative HLA-DRB1\*0405-binding 9-amino-acid portions in the amino acid sequence of said WT1 include the 9-amino-acid portions derived from WT1 as shown in SEQ ID NOS: 2-23. Thus, as a specific embodiment of the peptide of the present invention, the present invention provides a 5 peptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23, and which binds to HLA-DRB1\*0405 and induces helper T cells.

There are no limitations regarding the length of such a peptide on the condition that said peptide is a partial peptide of WT1 and comprises 10 an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23, and has an activity of binding to HLA-DRB1\*0405 and inducing helper T cells. As mentioned above, a peptide of about 9 amino acids with a binding motif can accommodate in a peptide-binding groove with the both ends extruding from the both sites of groove, and hence there are essentially no limitations 15 regarding the length of the peptides capable of binding to MHC class II molecule. However, long peptides are generally cleaved by peptidases, and the MHC class II-binding peptides having been reported so far are about 10 - 25 amino acids in length (*Immunogenetics*, 41,178-228 (1995), *Biochimica et Biophysica Acta* 1316, 85-101 (1996), *Immunology*, 96, 1-9 (1999). 20 *Peptides*, Vol.19, 179-198 (1998), *immunobiology*, 5th Edt., 116-117, Garland Publishing (2001)). Taking this into account, the peptides of the present invention preferably consist of about 10 - 25 amino acids, and more preferably about 13 - 17 amino acids.

Accordingly, examples of a preferred embodiment of the peptide of 25 the present invention which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23 include partial peptides derived from WT1 consisting of 10 - 25 amino acids (preferably, 13 - 17 amino-acids), which comprise an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23, and which have an activity of binding to HLA-DRB1\*0405 and inducing 30 helper T cells.

Examples of more preferred embodiments include partial peptides derived from WT1 consisting of 10 - 25 amino acids (preferably, 13 - 17 amino-acids), which comprise an amino acid sequence set forth in SEQ ID NO: 12, and which have an activity of binding to HLA-DRB1\*0405 and inducing helper T cells. Examples of still more preferred embodiments include partial peptides derived from WT1 consisting of 16 - 25 amino acids (preferably, 16 - 17 amino-acids), which comprise the amino acid sequence set forth in SEQ ID NO: 24, and which have an activity of binding to HLA-DRB1\*0405 and inducing helper T cells. The amino acid sequence set forth in SEQ ID NO: 24 represents a 16-amino-acid partial peptide derived from WT1 and includes the amino acid sequence set forth in SEQ ID NO: 12.

Further preferred embodiment is the peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24.

The peptides of the present invention may be altered as appropriate within a range that the activity is maintained. As used herein the "alteration" of amino acid residue means substitution, deletion and/or addition of amino acid residue(s) (the addition is inclusive of addition of amino acid(s) at the N- and/or C-terminus of a peptide). The substitution of amino acid residue(s) is preferred. When the alteration involves substitution of an amino acid residue(s), any number of amino acid residues at any position can be replaced on the condition that the activity as a helper peptide is retained. However, since a peptide which binds to HLA class II molecule is generally about 10 - 25 amino acids in length, the alteration is preferably involves one to several amino acids.

When altering amino acid residue by substitution, it is preferred that the amino acid residue at position 1, 4, 6 and/or 9 of a 9 amino acid peptide having the structure for the binding motif of HLA-DRB1\*0405 is substituted.

Specific examples of substitution-related peptides of the present

invention include peptides of 10 - 25 amino acids, which comprise an amino acid sequence wherein the amino acid residue at position 1, 4, 6 and/or 9 of an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23 is substituted by another amino acid residue, and which bind to an HLA-DRB1\*0405 and induce helper T cells.

Preferred examples include peptides of 10 - 25 amino acids, which comprise an amino acid sequence wherein the amino acid residue at position 1, 4, 6 and/or 9 of an amino acid sequence set forth in any one of SEQ ID NOS: 2 - 23 is substituted by an amino acid residue selected from the following amino acids:

phenylalanine, tyrosine, tryptophan, valine, isoleucine, leucine and methionine for the position 1;

valine, isoleucine, leucine, methionine, aspartic acid and glutamic acid for the position 4;

asparagine, serine, threonine, glutamine, lysine and aspartic acid for the position 6; and

aspartic acid, glutamic acid and glutamine for the position 9, and which bind to an HLA-DRB1\*0405 and induce helper T cells.

For example, the substitution of amino acid residue at position 1, 4, 6 and/or 9 can be conducted for the purpose of improving the binding activity to HLA-DRB1\*0405 or enhancing the activity of the above-mentioned natural-type helper peptides of the present invention which consist of partial sequences of WT1. The parts other than the substituted amino acid at position 1, 4, 6 and/or 9 of a peptide may remain to have the natural-type sequence (i.e., being kept to have the partial sequence of WT1), or may be further altered as far as the activity is retained.

More preferred examples include peptides of 10 - 25 amino acids, which comprise an amino acid sequence wherein the amino acid residue at position 1, 4, 6 and/or 9 of the amino acid sequence set forth in SEQ ID NO: 12 is substituted by an amino acid residue selected from the following

amino acids:

phenylalanine, tryptophan, valine, isoleucine, leucine and methionine for the position 1;

valine, isoleucine, methionine, aspartic acid and glutamic acid for the 5 position 4;

asparagine, serine, threonine, glutamine, lysine and aspartic acid for the position 6; and

aspartic acid, glutamic acid and glutamine for the position 9, and which bind to an HLA-DRB1\*0405 and induce helper T cells.

10 Still more preferred examples include peptides wherein the amino acid residue at position 3, 6, 8 and/or 11 of the 16-amino-acid partial peptide derived from WT1 set forth in SEQ ID NO: 24, which comprises the amino acid sequence set forth in SEQ ID NO: 12, is substituted by an amino acid residue selected from the following amino acids:

15 phenylalanine, tryptophan, valine, isoleucine, leucine and methionine for the position 3;

valine, isoleucine, methionine, aspartic acid and glutamic acid for the position 6;

asparagine, serine, threonine, glutamine, lysine and aspartic acid for the 20 position 8; and

aspartic acid, glutamic acid and glutamine for the position 11. Preferred examples may include peptides of 16 - 25 amino acids comprising the altered amino acid sequence derived from SEQ ID NO: 24.

The present invention also provides a peptide (so-called an epitope peptide) comprising a helper peptide (natural- or altered-peptide) of the 25 present invention together with a cancer antigen peptide.

Recently, it has been reported that an epitope peptide wherein a cancer antigen peptide(s) (also called as "CTL epitope") and a helper peptide(s) (also called as "helper epitope") are linked together can induce 30 CTLs efficiently. That is, helper T cells (CD4-positive T cells) activated by a

helper peptide exert various activities including induction of differentiation and maintenance of CTLs, and activation of effectors such as macrophages, etc, and hence are considered to enhance the CTL-induction by cancer antigens. As a concrete example of a peptide wherein a helper peptide(s) and cancer antigen peptide(s) are linked together, it is reported that a DNA (minigene) encoding an epitope peptide composed of HBV-originated HLA-A2-restricted antigen peptides (6 peptides), HLA-A11-restricted antigen peptides (3 peptides) and a helper peptide induced *in vivo* CTLs directed to the respective epitopes efficiently (*Journal of Immunology* 1999, 162: 3915-3925). Practically, a peptide wherein a CTL epitope (tumor antigen peptide corresponding to position 280-288 of melanoma antigen gp100) and a helper epitope (tetanus toxin-originated T helper epitope) are linked has been subjected to clinical test (*Clinical Cancer Res.*, 2001, 7:3012-3024).

Accordingly, as a specific embodiment, the peptides of the present invention also include epitope peptides comprising a helper peptide of the present invention and a cancer antigen peptide.

As the cancer antigen peptide, any of known cancer antigen peptides can be used; however, it is preferred to use a cancer antigen peptide derived from WT1 (natural or altered peptide). Concrete examples include WT1-derived peptides restricted to HLA-A1, -A0201, -A0204, -A0205, -A0206, -A0207, -A11, -A24, -A31, -A6801, -B7, -B8, -B2705, -B37, -Cw0401, -Cw0602, and the like.

Examples of WT1-derived cancer antigen peptides include those listed in Table II - Table XLVI of WO2000/18795 and altered peptides thereof which have the activity as a cancer antigen peptide (an activity of binding to an HLA antigen and inducing CTLs).

More concrete examples of WT1-derived cancer antigen peptides include the followings.

Cys Met Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 27)
Cys Tyr Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 28)

	Arg Met Phe Pro Asn Ala Pro Tyr Leu	(SEQ ID NO: 29)
	Arg Tyr Pro Ser Cys Gln Lys Lys Phe	(SEQ ID NO: 30)
	Ser Tyr Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 31)
	Ala Tyr Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 32)
5	Abu Tyr Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 33)
	Arg Tyr Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 34)
	Lys Tyr Thr Trp Asn Gln Met Asn Leu	(SEQ ID NO: 35)
	Arg Tyr Phe Pro Asn Ala Pro Tyr Leu	(SEQ ID NO: 36)
	Arg Tyr Pro Gly Val Ala Pro Thr Leu	(SEQ ID NO: 37)
10	Ala Tyr Leu Pro Ala Val Pro Ser Leu	(SEQ ID NO: 38)
	Asn Tyr Met Asn Leu Gly Ala Thr Leu	(SEQ ID NO: 39)
	Arg Val Pro Gly Val Ala Pro Thr Leu	(SEQ ID NO: 40)
	Arg Tyr Pro Ser Ser Gln Lys Lys Phe	(SEQ ID NO: 41)
	Arg Tyr Pro Ser Ala Gln Lys Lys Phe	(SEQ ID NO: 42)
15	Arg Tyr Pro Ser Abu Gln Lys Lys Phe	(SEQ ID NO: 43)
	Ser Leu Gly Glu Gln Gln Tyr Ser Val	(SEQ ID NO: 44)
	Asp Leu Asn Ala Leu Leu Pro Ala Val	(SEQ ID NO: 45)

In the above, "Abu" refers to "α-aminoacetic acid.

Among them, the peptides set forth in SEQ ID NOS: 27 and 29 are HLA-A24 antigen- and HLA-A2 antigen-binding peptides, and the peptides set forth in SEQ ID NOS: 44 and 45 are HLA-A2 antigen-binding peptides. The other peptides are HLA-A24 antigen-binding peptides.

Preferred cancer antigen peptide is the one set forth in SEQ ID NO: 27, 28, 29, 30, 44 or 45.

More specific examples of epitope peptides of the present invention include those which comprise a helper peptide that is a WT1-derived partial peptide of 10 - 25 amino acids comprising an amino acid sequence set forth in any one of SEQ ID NOS: 2-23 and has an activity of binding to HLA-DRB1\*0405 and inducing helper T cells, together with a cancer antigen peptide set forth in any one of SEQ ID NOS: 27-45 above.

Epitope peptides preferably comprise a helper peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24 together with a cancer antigen peptide set forth in any one of SEQ ID NOS: 27-45.

More preferably, epitope peptides comprise a helper peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24 together with a cancer antigen peptide set forth in any one of SEQ ID NOS: 27-30, 44 and 45.

The epitope peptides can be prepared by aforementioned usual method for peptide synthesis. It can also be prepared by a usual method for DNA synthesis and genetic engineering on the basis of sequence information of a polynucleotide encoding an epitope peptide wherein multiple epitopes are ligated. Specifically, an epitope peptide wherein a multiple epitopes are ligated can be prepared by inserting a polynucleotide encoding the peptide into a known expression vector, transforming a host cell with the resultant recombinant expression vector, culturing the transformants, and recovering the objective peptide from the culture. These processes can be conducted according to, for example, a method described in a literature (*Molecular Cloning*, T. Maniatis et al., CSH Laboratory (1983), *DNA Cloning*, DM. Glover, IRL PRESS (1985)), or that described hereinafter.

The activity of said epitope peptide as a helper peptide can be confirmed according to the above-mentioned method. Further, the activity of said epitope peptide as a cancer antigen peptide can be confirmed by subjecting the peptide to model animals for human described in WO02/47474 or *Int J. Cancer*: 100, 565-570, 2002.

An epitope peptide of the present invention is considered to be useful to establish more efficient treatment or prevention of cancer, because a helper peptide portion in the helper epitope peptide can activate helper T cells (CD4-positive T cells) to give activated helper T cells which exert various activities including induction of differentiation and maintenance of

CTLs and activation of effectors such as macrophages, whereby it enhances CTL-induction by cancer antigen peptides further.

The amino group of the N-terminal amino acid or the carboxyl group of the C-terminal amino acid of the above-described peptide of the present invention (natural-, altered- or epitope-peptide) may be modified. The peptides wherein the N-terminal and/or C-terminal amino acid residue is modified fall within the scope of the peptide of the present invention.

Examples of a group usable in the modification of amino group of the N-terminal amino acid include 1 to 3 groups selected from C<sub>1-6</sub> alkyl group, phenyl group, cycloalkyl group and acyl group. Acyl groups include C<sub>1-6</sub> alkanoyl group, C<sub>1-6</sub> alkanoyl group substituted by phenyl group, carbonyl group substituted by C<sub>5-7</sub> cycloalkyl group, C<sub>1-6</sub> alkylsulfonyl group, phenylsulfonyl group, C<sub>2-6</sub> alkoxycarbonyl group, alkoxycarbonyl group substituted by phenyl group, carbonyl group substituted by C<sub>5-7</sub> cycloalkoxy group, phenoxy carbonyl group, and the like.

Examples of peptides modified at the carboxyl group of C-terminal amino acid include esters and amides. Esters specifically include C<sub>1-6</sub> alkyl esters, C<sub>0-6</sub> alkyl esters substituted by phenyl group, C<sub>5-7</sub> cycloalkyl esters, and the like. Amides specifically include amides, amides substituted by one or two C<sub>1-6</sub> alkyl groups, amides substituted by one or two C<sub>0-6</sub> alkyl groups that are substituted by phenyl group, amides forming 5- to 7-membered azacycloalkane inclusive of nitrogen atom of amide group, , and the like.

The present invention also provides a polynucleotide encoding the above-mentioned peptide (natural-, altered- or epitope-peptide) of the present invention. The polynucleotide encoding a peptide of the present invention may be in the form of DNA or RNA. The polynucleotides of the present invention can be easily prepared on the basis of information about amino acid sequence of the present peptide or polynucleotide sequence of DNA encoding the same. Specifically, synthesis can be carried out using

usual method of DNA synthesis or amplification by PCR.

Concrete examples of polynucleotides include those encoding the above-mentioned epitope peptides. More specifically, examples of polynucleotide include those encoding epitope peptides which comprise a helper peptide that is a WT1-derived partial peptide of 10 - 25 amino acids comprising an amino acid sequence set forth in any one of SEQ ID NOS: 2-23 and has an activity of binding to HLA-DRB1\*0405 and inducing helper T cells, together with a cancer antigen peptide set forth in any one of SEQ ID NOS: 27-45 above.

Preferred examples include a polynucleotide encoding an epitope peptide which comprises a helper peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24 and a cancer antigen peptide set forth in any one of SEQ ID NOS: 27-45.

More preferred examples include a polynucleotide encoding an epitope peptide which comprise a helper peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24 and a cancer antigen peptide set forth in any one of SEQ ID NOS: 27-30, 44 and 45.

The "polynucleotide encoding the peptide of the present invention" encompasses polynucleotides that can hybridize under the stringent conditions to the complementary sequence of the said polynucleotide and that encode peptides which have activities equivalent to the peptide of the present invention. In relation to "hybridize under the stringent condition", the "hybridization" herein used can be carried out according to conventional method described in, for example, Sambrook J., Frisch E. F., Maniatis T. ed. *Molecular Cloning* 2nd edition, Cold Spring Harbor Laboratory press. The term "stringent conditions" means that hybridization is conducted in a solution containing 6xSSC (10 x SSC = 1.5 M NaCl, 1.5 M trisodium citrate), 50% formamide at 45°C, followed by washing in a solution of 2xSSC at 50°C (*Molecular Biology*, John Wiley & Sons, N. Y. (1989), 6.3.1-6.3.6)), or the like.

A recombinant expression vector for expressing the peptide of the present invention can be constructed by incorporating a polynucleotide prepared above into an expression vector.

As expression vectors usable herein include plasmids, phage vectors, virus vectors, and the like.

When the host is Escherichia coli, examples of vector include plasmid vectors such as pUC118, pUC119, pBR322, pCR3, and the like; and phage vectors such as λZAPII, λgt11, and the like. When the host is yeast, examples of vector include pYES2, pYEUra3, and the like. When the host is insect cells, examples of vector include pAcSGHisNT-A, and the like. When the host is animal cells, examples of vector include plasmid vectors such as pKCR, pCDM8, pGL2, pcDNA3.1, pRc/RSV, pRc/CMV, and the like; and virus vectors such as retrovirus vector, adenovirus vector, adeno-associated virus vector, and the like.

The expression vector may optionally contain a factor(s) such as promoter capable of inducing expression, a gene encoding a signal sequence, a marker gene for selection, terminator, and the like.

Furthermore, the expression vector may contain an additional sequence for allowing the peptide to express as a fusion protein with thioredoxin, His tag, GST (glutathione S-transferase), or the like, so as to facilitate the isolation and purification. Vectors usable in such a case include GST fusion protein vectors containing an appropriate promoter (lac, tac, trc, trp, CMV, SV40 early promoter, etc) that functions in host cells, such as pGEX4T; vectors containing Tag sequence (Myc, His, etc) such as pcDNA3.1/Myc-His; and vectors capable of expressing a fusion protein between thioredoxin and His tag such as pET32a.

Transformed cells containing the vector of the present invention can be prepared by transforming host cells with an expression vector obtained in the above.

Host cells usable herein include Escherichia coli, yeast, insect cells

and animal cells. Examples of Escherichia coli include strains of E. coli K-12 such as HB101, C600, JM109, DH5 $\alpha$  and AD494 (DE3). Examples of yeast include *Saccharomyces cerevisiae*. Examples of animal cells include L929, BALB/c3T3, C127, CHO, COS, Vero and Hela cells. Examples of insect cells include sf9.

Introduction of an expression vector into host cells can be done using a conventional method suited for the respective host cells above. Specifically, introduction can be done using calcium phosphate method, DEAE-dextran method, electroporation method, and a method using lipid 10 for gene transfer (Lipofectamine, Lipofectin; Gibco-BRL). Following the introduction, the cells are cultured in a conventional medium containing a selection marker, whereby transformants containing the expression vector can be selected.

The peptide of the present invention can be produced by culturing 15 the transformed cells under appropriate conditions (conditions under which peptides can be expressed). The resultant peptide may be further isolated and purified according to standard biochemical purification procedures. The purification procedures include salting out, ion exchange chromatography, absorption chromatography, affinity chromatography, gel filtration chromatography, etc. When the polypeptide of the present 20 invention has been expressed as a fusion peptide with thioredoxin, His tag, GST, or the like, as mentioned above, the peptide can be isolated and purified by appropriate purification procedures making use of the characteristics of the fusion protein or tags.

25 The present invention provides an antibody which specifically binds to a peptide of the present invention. The antibody of the present invention is not restricted to any form and may be polyclonal or monoclonal antibody raised against a peptide of the present invention as an antigen.

As mentioned above, there is no limitation regarding the antibody of 30 the present invention on the condition that it specifically binds to a peptide

of present invention. Examples of preferred antibody include those specifically bind to a helper peptide that is a WT1-derived partial peptide of 10 - 25 amino acids comprising an amino acid sequence set forth in any one of SEQ ID NOS: 2-23 and has an activity of binding to HLA-DRB1\*0405 and inducing helper T cells. Antibodies specifically bind to a helper peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24 is more preferred.

Methods of preparation of antibodies are well known in the art and the antibodies of the present invention can be prepared according to any one of conventional methods (*Current protocols in Molecular Biology* edit. Ausubel et al. (1987) Publish. John Wiley and Sons. Section 11.12-11.13, Antibodies; *A Laboratory Manual*, Lane, H. D. et al., ed., Cold Spring Harber Laboratory Press, New York 1989).

Specifically, antibodies of the present invention can be obtained by immunizing a non-human animal such as rabbit using a peptide of the present invention as an antigen, and recovering the antibodies from serum of the immunized animal in a conventional manner. In the case of monoclonal antibodies, they can be obtained by immunizing a non-human animal such as mouse with a peptide of the present invention, subjecting the resultant splenocytes to cell fusion with myeloma cells, and recovering monoclonal antibodies from the resultant hybridoma cells (*Current protocols in Molecular Biology* edit. Ausubel et al. (1987) Publish. John Wiley and Sons. Section 11.4-11.11).

The antibodies against the peptide of the present invention can also be produced while enhancing the immunological response using different adjuvants depending on the host. Examples of adjuvants include Freund adjuvants; mineral gels such as aluminium hydroxide; surfactants such as lysolecithin, Pluronic® polyol, polyanion, peptide, oil emulsion, keyhole limpet hemocyanin and dinitorophenol; human adjuvants such as BCG (Bacille de Calmette-Guerin) or Corynebacterium, etc.

As mentioned above, antibodies that recognize a peptide of the present invention and antibodies that neutralize the activity thereof can easily be prepared by immunizing an animal in a conventional manner. The antibodies may be used in affinity chromatography, immunological diagnostic method, and the like. Immunological diagnostic method may be selected as appropriate from immunoblotting, radioimmunoassay (RIA), enzyme-linked immunosorbent assay (ELISA), a fluorescent or luminescent assay, and the like. The immunological diagnostic method is effective in the diagnosis of cancer expressing WT1 gene such as gastric cancer, colon cancer, lung cancer, breast cancer, embryonal cancer, skin cancer, bladder cancer, prostate cancer, uterine cancer, cervical cancer, ovarian cancer, and the like.

The present invention provides a pharmaceutical composition comprising a peptide (natural-, altered-, and epitope-type peptides) of the present invention, an expression vector containing a polynucleotide of the present invention or a cell containing an expression vector of the present invention, in association with a pharmaceutically acceptable carrier. The pharmaceutical composition can be used effectively as an inducer of helper T cells or an enhancer of cancer vaccine efficacy, as described in detail below.

(1) An inducer of helper T cells comprising as an active ingredient a peptide of the present invention (an enhancer of cancer vaccine efficacy)

The peptide of the present invention has an activity of inducing helper T cells, and the induced helper T cells in turn are able to enhance the CTL-inducing activity, which is the effects of cancer vaccine, through the induction of differentiation and maintenance of CTLs and the activation of effectors such as macrophages. Thus, the present invention provides an enhancer of cancer vaccine efficacy comprising as an active ingredient a peptide of the present invention (pharmaceutical composition as an agent for enhancing efficacy of cancer vaccine). When the enhancer of the

present invention is administered to an HLA-DRB1\*0405-positive and WT1-positive patient, the peptide is presented to HLA-DRB1\*0405 antigen of an antigen-presenting cell; specific helper T cells (CD4-positive T cells) recognizing a complex of the peptide and HLA-DRB1\*0405 antigen are induced and activated; and the activated helper T cells can exert the activity concerning induction of differentiation and maintenance of CTLs and activation of effectors such as macrophages. In this manner, the activity of activating and inducing CTLs as the effect of cancer vaccine is enhanced.

The enhancer of cancer vaccine efficacy of the present invention can be used in the prevention or treatment of cancer accompanied by elevated expression level of WT1 gene, for example, blood cancers such as leukemia, myelodysplastic syndrome, multiple myeloma and malignant lymphoma, and solid cancers such as gastric cancer, colon cancer, lung cancer, breast cancer, embryonal cancer, hepatic cancer, skin cancer, bladder cancer, prostate cancer, uterine cancer, cervical cancer, and ovarian cancer.

The enhancer of cancer vaccine efficacy of the present invention can be administered concurrently with, before or after the administration of cancer vaccine.

The enhancer of cancer vaccine efficacy comprising as an active ingredient a peptide of the present invention may contain as an active ingredient a helper peptide(s) or an epitope peptide wherein a peptide(s) is ligated with a cancer antigen peptide(s) (CTL epitope(s)). As mentioned above, it has recently been shown that an epitope peptide wherein a cancer antigen peptide (CTL epitope) and a helper peptide (helper epitope) can induce CTLs efficiently. When an epitope peptide of this form is administered, said peptide is incorporated into antigen-presenting cells; among the antigen peptides generated by intracellular degradation, helper peptides bind to MHC class II antigen (HLA-DRB1\*0405) while cancer antigen peptides to MHC class I antigen; and respective complexes thus

formed are presented on the surface of antigen-presenting cells in high density. When helper T cells recognize the complex of HLA-DRB1\*0405 antigen and helper peptide, the CTL-inducing activity that is the effect of cancer vaccine is further enhanced as a result of induction of differentiation and maintenance of CTLs and the activation of effectors such as macrophages. On the other hand, when CTLs recognize the complex of cancer antigen peptides and MHC class I antigen, CTLs proliferate and destroy the cancer cells. Thus, the pharmaceutical composition of the present invention comprising as an active ingredient an epitope peptide of the present invention can be used as a cancer vaccine *per se*, as well as an enhancer of cancer vaccine efficacy.

The enhancer of cancer vaccine efficacy which comprises as an active ingredient a peptide of the present invention may be administered together with a pharmaceutically acceptable carrier, for example, an appropriate adjuvant, or in the form of particles so that the cellular immunity can be established effectively. As an adjuvant, those described in a literature (*Clin. Microbiol. Rev.*, 7:277-289, 1994), and the like are applicable. Concrete examples include microorganism-derived components, cytokines, plant-derived components, marine organism-derived components, mineral gels such as aluminium hydroxide, surfactants such as lysolecithin and Pluronic® polyols, polyanions, peptides, oil emulsion (emulsion preparations) and the like. Liposomal preparations, particulate preparations in which the ingredient is bound to beads having a diameter of several  $\mu\text{m}$ , preparations in which the ingredient is attached to lipids, and the like, are also contemplated.

Administration may be achieved, for example, intradermally, subcutaneously, intramuscularly, or intravenously. Although the dosage of the peptide of the present invention in the formulation may be adjusted as appropriate depending on, for example, the disease to be treated, the age and the body weight of a patient, it is usually within the range of

0.0001 mg - 1000 mg, preferably 0.001 mg - 1000 mg, more preferably 0.1 mg - 10 mg, which can be preferably administered once in every several days to every several months.

The present invention also provides a pharmaceutical composition comprising a combination of a peptide of the present invention and a cancer antigen peptide. According to the combined use of the present invention, the effect of a cancer antigen peptide as cancer vaccine (i.e., activity of inducing and activating CTLs) is enhanced by the peptide of the present invention, and the treatment or prevention of cancer can be achieved more effectively.

The term "combination" encompasses the both forms where a peptide of the present invention and a cancer antigen peptide are administered in a mixed form or discrete forms.

Administration of the peptides in the mixed form can be conducted using a previously prepared formulation containing the peptides as a mixture, or combining previously prepared formulations each comprising the respective peptides before use.

In the case where peptides are administered in discrete forms, the discrete formulations may be administered successively with a time-interval, or administered concurrently. When administration is conducted with a time-interval, a peptide of the present invention (enhancer of cancer vaccine efficacy) and a cancer antigen peptide (cancer vaccine) may be administered in this order or in reverse order.

An embodiment of the combination of a peptide of the present invention and a cancer antigen peptide includes a kit.

As a cancer antigen peptide usable in combination with a peptide of the present invention, any cancer antigen peptides conventionally known can be used, and examples include WT1-derived cancer antigen peptides (natural-, altered-type). Concrete examples include a cancer antigen peptide set forth in any one of SEQ ID NOS: 27 - 45, preferably, SEQ ID

NOS: 27 - 30, 44 and 45.

(2) Inducer of helper T cells (enhancer of cancer vaccine efficacy) comprising as an active ingredient an expression vector of the present invention

5 An expression vector containing a polynucleotide encoding a peptide of the present invention, similar to the above-mentioned peptide of the present invention, has an activity of inducing helper T cells and is useful as an active ingredient of an enhancer of cancer vaccine efficacy of the present invention. Thus, the present invention provides an enhancer of  
10 cancer vaccine efficacy (i.e., a pharmaceutical composition as an agent enhancing efficacy of cancer vaccine) comprising as an active ingredient an expression vector containing a polynucleotide encoding a peptide of the present invention.

Recently, a polynucleotide encoding an epitope peptide wherein a cancer antigen peptide (CTL epitope) and a helper peptide (helper epitope) are ligated has been shown to have an activity of inducing CTLs *in vivo* efficiently. For example, it is reported that a DNA (minigene) encoding an epitope peptide wherein HBV-originated HLA-A2-restricted antigen peptides (6 peptides), HLA-A11-restricted antigen peptides (3 peptides) and a helper epitope are ligated induced *in vivo* CTLs directed to the respective epitopes efficiently (*Journal of Immunology* 1999, 162: 3915-3925).

Accordingly, an active ingredient of enhancer of cancer vaccine efficacy can be obtained by incorporating a polynucleotide encoding the above-described epitope peptide of present invention into an appropriate expression vector.

When administering an expression vector containing a polynucleotide of the present invention as an active ingredient of enhancer of cancer vaccine efficacy, the following methods can be used.

As a method for introducing an expression vector containing the polynucleotide of the present invention into cells, any means including

those utilizing viral vectors or other methods are applicable (*Nikkei-Science*, April, 1994, p20-45; *Gekkan-Yakuji*, 36(1), p23-48 (1994); *Jikken-Igaku-Zokan*, 12(15), 1994, and references cited therein).

Examples of means utilizing a viral vector include those wherein a DNA of the present invention is incorporated into DNA or RNA virus such as retrovirus, adenovirus, adeno-associated virus, herpes virus, vaccinia virus, poxvirus, poliovirus, or Sindbis virus, and then introduced into cells. Above all, a method utilizing retrovirus, adenovirus, adeno-associated virus, or vaccinia virus, or the like, is particularly preferred.

Examples of other methods include those wherein an expression vector is directly injected intramuscularly (DNA vaccination), liposome method, Lipofectin method, microinjection, calcium phosphate method and electroporation. DNA vaccination and liposome method are particularly preferred.

Regarding a method to make the expression vector of the present invention act as a medicament in practice, there are an *in vivo* method wherein the expression vector is directly introduced into the body and an *ex vivo* method wherein the expression vector is introduced extracorporeally into a certain cells removed from human, and the cells are reintroduced into the body (*Nikkei-Science*, April, 1994, 20-45; *Gekkan-Yakuji*, 36(1), 23-48 (1994); *Jikkenn-Igaku-Zokan*, 12(15), 1994; and references cited therein). The *in vivo* method is more preferred.

In the case of *in vivo* method, the administration can be effected through any appropriate routes depending on the disease and symptoms to be treated. For example, it may be administered via intravenous, intraarterial, subcutaneous, intracutaneous, intramuscular route, or the like. When the administration is carried out by *in vivo* method, the compositions may be administered in various forms such as solution, and are typically formulated, for example, in the form of injection containing, as an active ingredient, an expression vector of the present invention to which

conventional carriers may also be added, if necessary. As for the liposomes or membrane-fused liposomes (such as Sendai virus (HVJ)-liposomes) containing an expression vector of the present invention, they may be in the form of liposomal formulation such as suspension, frozen drug, centrifugally-concentrated frozen drug, or the like.

Although the content of an expression vector in a formulation may be adjusted as appropriate depending on, for example, the disease to be treated, age and body weight of a patient, usually, 0.0001 mg - 100 mg, preferably 0.001 mg - 10 mg of an expression vector of the present invention can be administered once in every several days to every several months.

When the above-mentioned expression vector of the present invention is administered to an HLA-DRB1\*0405-positive and WT1-positive patient, the peptide of the present invention is presented to HLA-DRB1\*0405 antigen of an antigen-presenting cell; specific helper T cells (CD4-positive T cells) recognizing a complex of the peptide and HLA-DRB1\*0405 antigen are induced and activated; the activated helper T cells can exert the activity concerning induction of differentiation and maintenance of CTLs and activation of effectors such as macrophages. In this manner, the activity of inducing CTLs as an effect of cancer vaccine is enhanced. The enhancer of cancer vaccine efficacy comprising as an active ingredient an expression vector containing a polynucleotide of the present invention can be used in the prevention or treatment of cancer accompanied by elevated expression level of WT1 gene, for example, blood cancers such as leukemia, myelodysplastic syndrome, multiple myeloma and malignant lymphoma, and solid cancers such as gastric cancer, colon cancer, lung cancer, breast cancer, embryonal cancer, hepatic cancer, skin cancer, bladder cancer, prostate cancer, uterine cancer, cervical cancer, and ovarian cancer.

In the above case where an expression vector containing a

polynucleotide encoding an epitope peptide is administered, antigen presenting cells incorporate the same and generate antigen peptides through intracellular degradation, of which helper peptides and cancer antigen peptides bind to MHC class II antigen (HLA-DRB1\*0405) and MHC class I antigen, respectively, to form complexes. The so formed complexes are presented on the surface of antigen presenting cells in high density. When helper T cells recognize the complex of HLA-DRB1\*0405 antigen and helper peptide, the CTL-inducing activity that is the effect of cancer vaccine is further enhanced through the induction of differentiation and maintenance of CTLs and the activation of effectors such as macrophages. On the other hand, when CTLs recognize the complex of cancer antigen peptides and MHC class I antigen, CTLs proliferate and destroy the cancer cells. Thus, the pharmaceutical composition of the present invention comprising as an active ingredient an expression vector containing a polynucleotide encoding an epitope peptide of the present invention can be used as a cancer vaccine *per se*, as well as an enhancer of cancer vaccine efficacy.

The present invention also provides a peptide consisting of 10 - 25 contiguous amino acids in the amino acid sequence of human WT1 set forth in SEQ ID NO: 1, said peptide binding to HLA-DRB1\*1502 and inducing helper T cells. The present invention encompasses antigen peptides binding to HLA-DRB1\*1502 wherein the N-terminal and/or C-terminal amino acid residue is modified or those wherein a particular amino acid residue(s) is altered.

The synthesis and determination of activity of antigen peptides binding to HLA-DRB1\*1502 of the present invention can be carried out in a manner similar to that described in relation to the above-mentioned antigen peptides binding to HLA-DRB1\*0405 of the present invention.

The HLA-DRB1\*1502-binding antigen peptides of the present invention is a partial peptide which consists of 10 - 25 contiguous amino

acids in the amino acid sequence of human WT1 set forth in SEQ ID NO: 1. Preferred peptides are those consisting of 13 - 17 contiguous amino acids in the amino acid sequence of human WT1.

The present invention is based on the finding that human WT1 contains an antigen peptide portion having activity of binding to HLA-DRB1\*1502 and inducing helper T cells. Search for 9-amino-acid portions potentially binding to HLA-DRB1\*1502 (9-amino-acid portions capable of being accommodated in a peptide-binding groove of MHC class II molecule) was conducted using a software for predicting MHC class II binding peptides (Propred, *Bioinformatics* 17: 1236, 2001). Examples of the identified 9-amino-acid portions of WT1 are shown in SEQ ID NOS: 46-56. Thus, specific examples of HLA-DRB1\*1502-binding antigen peptides of the present invention include a peptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 46 - 56, and which binds to HLA-DRB1\*1502 and induces helper T cells.

The said peptides preferably consist of about 10 - 25 amino acids, and more preferably about 13 - 17 amino acids. Examples of more preferred embodiments include partial peptides derived from WT1 consisting of 10 - 25 amino acids (preferably, 13 - 17 amino-acids), which comprise the amino acid sequence set forth in SEQ ID NO: 50, and which have an activity of binding to HLA-DRB1\*1502 and inducing helper T cells. Examples of still more preferred embodiments include partial peptides derived from WT1 consisting of 16 - 25 amino acids (preferably, 16 - 17 amino-acids), which comprise the amino acid sequence set forth in SEQ ID NO: 24, and which have an activity of binding to HLA-DRB1\*1502 and inducing helper T cells. The amino acid sequence set forth in SEQ ID NO: 24 represents a 16-amino-acid partial peptide derived from WT1 and includes the amino acid sequence set forth in SEQ ID NO: 50.

Further preferred embodiment is the WT1<sub>332-347</sub> peptide consisting of the amino acid sequence set forth in SEQ ID NO: 24.

The said WT<sub>1332-347</sub> peptide is a promiscuous helper peptide which binds not only to HLA-DRB1\*0405 molecule but also to HLA-DRB1\*1502 molecule. Accordingly, WT<sub>1332-347</sub> is a helper peptide applicable to patients having HLA-DRB1\*0405 and those having HLA-DRB1\*1502 as well, and hence is useful from the viewpoint of wide application range of patients.

The epitope peptide, polynucleotide, antibody, and pharmaceutical composition regarding the HLA-DRB1\*1502-binding antigen peptide of the present invention can be made and use (put into effect) in a manner similar to above-mentioned HLA-DRB1\*0405-binding antigen peptide of the present invention.

## EXAMPLES

The present invention is further illustrated by the following examples, but should not be construed as being limited thereto.

### Example 1

#### 1. Preparation of Dendritic Cells

Peripheral blood mononuclear cells (PBMCs) were isolated by density gradient centrifugation with Ficoll-Paque from blood of an HLA-DRB1\*0405-positive healthy volunteer. The resultant 8x10<sup>6</sup> PBMCs were suspended in 2 ml of X-VIVO 15<sup>TM</sup> medium (Camblex) containing 1% AB serum, seeded in a 6-well culture plate, and cultured for 2 hours. After cultivation, non-adherent cells were removed, and the adherent cells were washed with Hanks solution. Adherent cells were cultured in X-VIVO 15<sup>TM</sup> medium containing 1% AB serum, 1000 U/ml IL-4 and 1000 U/ml GM-CSF. On days 2 and 4 of cultivation, one-half of medium was replaced by fresh medium. On day 6, TNF- $\alpha$  was added to make the final concentration of 100 U/ml. Cells existing on day 7 were used as dendritic cells in the experiment.

#### 2. Preparation of CD4-positive T Cells (Helper T Cells)

Blood obtained from the same healthy volunteer as in (1) above was

used. Blood was diluted by 2-times with RPMI medium. To about 100 ml of the diluted blood was added antibody cocktail, RosetteSep™ (Stemcell) for separation of CD4-positive T cells, and the mixture was left to stand at room temperature for 20 minutes. CD4-positive T cells were then collected  
5 by density gradient centrifugation with Ficoll-Paque.

3. Induction of WT1 Peptide-specific CD4-positive T cells

Amino acid sequence of WT1 protein (NCBI database, Accession No. P19544, XP\_034418, SEQ ID NO: 1) was searched for peptides potentially binding to HLA-DRB1\*0405 using a prediction program (Propred,  
10 *Bioinformatics* 17: 1236, 2001). Three peptides were selected and synthesized. These peptides have the same amino acid sequences as those present at the following positions of WT1:

Position 172-186: PNHSFKHEDPMGQQG (WT1<sub>172-186</sub>, SEQ ID NO: 25);

Position 225-243: NLYQMTSQLECMTWNQMNL (WT1<sub>225-243</sub>, SEQ ID NO:  
15 26); and

Position 332-347: KRYFKLSHLQMHSRKH (WT1<sub>332-347</sub>, SEQ ID NO: 24).

Dendritic cells prepared in (1) above were seeded in 24-well culture plate at 3x10<sup>5</sup> cells/well, and a peptide of SEQ ID NO: 24 was added up to 50 µg/ml. After 4-hour-cultivation, cell growth was stopped by X-ray irradiation (25Gy). CD4-positive cells prepared in (2) above were added to each well at 3x10<sup>6</sup> cells/well and cocultured with dendritic cells. As medium, X-VIVO 15™ medium containing 1% AB serum was used. After the cultivation was started, one half of medium was replaced with fresh medium every 2 days and IL-2 was added up to 20 U/ml. On days 7 and  
20 14 from the beginning of cultivation, T cells were collected and seeded in 24-well plate at 3x10<sup>6</sup> cells/well, and thereto were added 3x10<sup>5</sup> dendritic cells having been pulsed with 20 µg/ml of a peptide (SEQ ID NO: 24) and undergone X-ray irradiation (25Gy). The cells were then cocultured. As medium, X-VIVO 15™ medium containing 1% AB serum and 20 U/ml IL-  
25 30 was used.

After the third stimulation, T cells were recovered and seeded in 96-well plate at  $3 \times 10^4$  cells/well. Dendritic cells having been pulsed with 20  $\mu\text{g}/\text{ml}$  of a peptide (SEQ ID NO: 24) and undergone X-ray irradiation (25Gy) were added at  $3 \times 10^4$  cells/well, followed by coculture. As a negative control group, T cells were cocultured with dendritic cells not pulsed with the peptide, and as a positive control group, 0.2% PHA was added instead of dendritic cells. After 80-hour-cultivation, [ $^3\text{H}$ ]-thymidine (37kBq/well) was added, and the cells were cultured for another 16 hours. [ $^3\text{H}$ ]-thymidine incorporated by cells was then measured using  $\beta$ -scintillation counter. The results are shown in Fig. 1. CD4-positive T cells stimulated with a peptide at position 332-347 of WT1 (WT<sub>1</sub><sub>332-347</sub>, SEQ ID NO: 24) showed proliferative response when cocultured with dendritic cells pulsed with WT<sub>1</sub><sub>332-347</sub>. However, CD4-positive T cells did not show proliferative response when cocultured with dendritic cells not pulsed with the peptide, or dendritic cells pulsed with a peptide having amino acid sequence of SEQ ID NO: 25 or 26 which is different from that of SEQ ID NO: 24. These results demonstrate that the WT<sub>1</sub><sub>332-347</sub> peptide (SEQ ID NO: 24) induces specific CD4-positive T cells as an antigen peptide.

#### Example 2

##### Establishment of CD4-positive T-cell Lines Specific for WT1 Peptides

Dendritic cells prepared in a manner similar to Example 1 were seeded in 96-well plate at  $10^4$  cells/well, and then CD4-positive T cells induced by WT<sub>1</sub><sub>332-347</sub> peptide (SEQ ID NO: 24) were seeded at  $10^3$  cells/well. As medium, X-VIVO 15<sup>TM</sup> medium containing 1% AB serum, 20 U/ml IL-2 and 5  $\mu\text{g}/\text{ml}$  PHA was used. CD4-positive T-cell line was established by continued cultivation and named as "G2 cell line". Responsiveness of G2 cell line to dendritic cells pulsed with a peptide was measured by a similar method to Example 1. The results are shown in Fig. 2. G2 cell line showed proliferative response when cocultured with dendritic cells pulsed with WT<sub>1</sub><sub>332-347</sub> peptide, but did not when cocultured

with dendritic cells not-pulsed with the peptide.

These results demonstrate that G2 cell line is a CD4-positive T-cell line specific for WT1<sub>332-347</sub> peptide.

### Example 3

#### 5 Antigen Presentation of WT1 Peptide to HLA-DR Molecule

Peripheral blood mononuclear cells (PBMCs) were isolated by density gradient centrifugation with Ficoll-Paque from blood of an HLA-DRB1\*0405-positive healthy volunteer in a manner similar to Example 1. PBMCs were then seeded in 24-well plate at 10<sup>7</sup> cells/well. As medium, 10 RPMI1640 medium containing 10% FCS and 55 µM 2ME was used. After adding medium containing Epstein-Barr virus (EBV), cultivation was continued for another 4 weeks to establish B-cell line transformed with EBV, which cell line was named as "B-LCL(-) cell". EBV was prepared from culture supernatant of B95-8 (JCRB Cell Bank No. 9123), a cell line that produces EBV. B-LCL(-) cells were adjusted to 3x10<sup>7</sup> cells/mL, and thereto were added medium containing virus expressing WT1 gene and then polypropylene (final concentration, 8 µg/mL), and the mixture was added to a 24-well plate at 1 ml/well. After 16-hour-cultivation, 1 ml of fresh medium was added to each well, and cultivation was continued. To 15 each well was added G418 (neomycin) up to 0.7 µg/mL, and the plate was cultured for 5 to 7 days, when cells into which the gene was introduced were selected. The selected B-cell line expressing WT1 was named as "B-LCL(+) cell". The amount of WT1 gene expressed by B-LCL(-) and B-LCL(+) cells was measured by RT-PCR technique according to the method 20 described in *Blood*, 89:1405, 1997. The measurements were converted by assuming the expression amount of K562 cell line as the positive control to be 1. The resulting value for B-LCL(-) cells was 1.6x10<sup>-4</sup> while that for B-LCL(+) cells 3.2, indicating that WT1 gene is highly expressed. Responsiveness of G2 cells to B-LCL(+) cells was examined in a manner 25 similar to Example 2. In a test group, B-LCL(+) cells were treated with 30

anti-HLA-DR antibody before mixing with G2 cells to confirm the HLA-DR-restriction. The results are shown in Fig. 3. It was revealed that G2, which is a CD4-positive T-cell line positive for the peptide, shows proliferative response when cocultured with B-LCL(+) cells expressing endogenous WT1 genes, and that said response is inhibited by anti-HLA-DR antibody. These results demonstrate that WT<sub>1332-347</sub> peptide is intracellularly generated from WT1 protein and endogenously presented as an antigen to HLA-DR molecule.

Example 4

10 Establishment of CD4-positive T-cell Lines E04.1 Specific for WT<sub>1332-347</sub> Peptide

Dendritic cells were prepared using blood isolated from an HLA-DRB1\*0405-positive healthy volunteer in a manner similar to Example 1 except that the final concentration of TNF- $\alpha$  added on day 6 was 200 IU/ml. CD4-positive T cells were prepared using blood obtained from the same healthy volunteer as that used for the preparation of dendritic cells. CD4-positive T cells were separated according to the instructions of RosetteSep (StemCell) for separation of CD4-positive T cells.

The above-described dendritic cells and CD4-positive T cells were used to induce CD4-positive T cells specific for a WT1 peptide (SEQ ID NO: 24, WT<sub>1332-347</sub>) in a manner similar to Example 1. The resultant CD4-positive T cells specific for WT<sub>1332-347</sub> peptide were cultured continuously by limiting dilution technique to establish CD4-positive T-cell line E04.1. As feeder cells in the limiting dilution technique, PBMCs prepared in a manner similar to Example 1 and treated by X-ray irradiation were seeded at 1x10<sup>5</sup> cells/well. As medium, X-VIVO 15™ medium containing 20 IU/ml IL-2 and 5  $\mu$ g/ml PHA was used.

30 Responsiveness of E04.1 cell line to dendritic cells pulsed with WT<sub>1332-347</sub> peptide was measured by a similar method to Example 1 except that cultivation was continued for 18 hours after adding [<sup>3</sup>H]-thymidine.

The results are shown in Fig. 4. E04.1 cells showed proliferative response when cocultured with dendritic cells pulsed with WT<sub>1332-347</sub> peptide but did not when cocultured with dendritic cells not-pulsed with the peptide. These results demonstrate that E04.1 cell is a CD4-positive T-cell line specific for WT<sub>1332-347</sub> peptide.

5           **Example 5**

Specific Binding of WT<sub>1332-347</sub> Peptide to HLA-DR

E04.1 cells established in Example 4 were seeded in 96-well culture plate at 1x10<sup>4</sup> cells/well. B cell line B-LCL (-) cells established from blood of an HLA-DRB1\*0405-positive healthy volunteer in Example 3 were pulsed with WT<sub>1332-347</sub> peptide at a concentration of 20 μg/ml and treated by X-ray irradiation, seeded in 96-well plate at 3x10<sup>4</sup> cells/well, and cocultured with E04.1 cells. As a negative control group, B-LCL (-) cells not pulsed with the peptide were cocultured with E04.1 cells.

15           As test groups, B-LCL (-) cells having been pulsed with WT<sub>1332-347</sub> peptide and undergone X-ray irradiation were treated with 20 μg/ml of anti-HLA-DR antibody (G46.6, BD ParMingen), anti-H LA-class I antibody (G46-2.6, BD ParMingen), or anti-HLA-DQ antibody (SPVL3, Immunotech) for 30 minutes, and cocultured with E04.1 cells to confirm HLA-DR restricted nature. As a negative control group for antibody treatment, cells 20          treated with anti-mouse IgG antibody were cocultured with E04.1 cells in a similar manner.

25           Following cocultivation, growth of E04.1 cells was measured in a manner similar to Example 4. The results are shown in Fig. 5. E04.1 cells showed proliferative response when cocultured with B-LCL (-) cells pulsed with WT<sub>1332-347</sub> peptide. However, when WT<sub>1332-347</sub> peptide-pulsed B-LCL (-) cells were treated with anti-HLA-DR antibody, growth of cells was inhibited. Further, E04.1 cells showed proliferative response to WT<sub>1332-347</sub>-peptide-pulsed B-LCL (-) cells treated with other antibody, but did not 30          show proliferative response to B-LCL (-) cells not pulsed with the peptide.

These results demonstrate that WT<sub>1332-347</sub> peptide specifically binds to HLA-DR among HLA molecules, and induces growth of CD4-positive E04.1 cell line specific for WT<sub>1332-347</sub> peptide.

Example 6

5      Specific Binding of WT<sub>1332-347</sub> Peptide to HLA-DRB1\*0405

PBMCs were prepared from blood of HLA-DRB1\*0405-positive or -negative healthy volunteer in a manner similar to Example 4. PBMCs were then pulsed with 20  $\mu$ g/ml of WT<sub>1332-347</sub> peptide and subjected to X-ray irradiation, and seeded in 96-well plate at 3x10<sup>4</sup> cells/well. E04.1 cells 10 were then seeded into the 96-well plate at 1x10<sup>4</sup> cells/well, and the cells were cocultured. As a negative control group, PBMCs not pulsed with the peptide and E04.1 cells were cocultured.

Following cocultivation, growth of E04.1 cells was measured in a manner similar to Example 4. The results are shown in Fig. 6. Donor 1 15 (HLA-DRB1\*0405/0803) and Donor 2 (HLA-DRB1\*0405/0101) are HLA-DRB1\*0405-positive, and E04.1 cells cocultured with PBMCs isolated from each donor and pulsed with WT<sub>1332-347</sub> peptide showed proliferative response. On the other hand, Donor 3 (HLA-DRB1\*0101/1001) and Donor 4 (HLA-DRB1\*1201/0802) are HLA-DRB1\*0405-negative, and E04.1 cells 20 cocultured with PBMCs isolated from each donor and pulsed with WT<sub>1332-347</sub> peptide did not show proliferative response. Further, in all cases, no proliferative response was observed when PBMCs not-pulsed with the peptide were used. The above results demonstrate that WT<sub>1332-347</sub> peptide 25 specifically binds to HLA-DRB1\*0405 among HLA-DRB1 molecules showing polymorphism, and induce the growth of WT<sub>1332-347</sub>-specific CD4-positive cell line E04.1.

Example 7

Antigen Presentation of WT<sub>1332-347</sub> Peptide to HLA-DRB1\*0405

B-LCL(-) cells (B-cell line) and B-LCL (+) cells (B-cell line expressing 30 WT1), which were established from blood of an HLA-DRB1\*0405-positive

healthy volunteer as described in Example 3, were each subjected to X-ray irradiation and seeded in 96-well plate at  $3 \times 10^4$  cells/well. E04.1 cells were seeded into each well at  $1 \times 10^4$  cells and cocultured. Growth response of E04.1 cells was then measured in a manner similar to Example 4. The results are shown in Fig. 7. E04.1 cells showed proliferative response when cocultured with B-LCL (+) cells expressing WT1, but not when cocultured with B-LCL (-) cells not-expressing WT1.

Next, B-LCL(-) or B-LCL (+) cells ( $1 \times 10^5$  cells each) having been induced apoptosis were cocultured for 16 hours with dendritic cells ( $3 \times 10^4$  cells) prepared from blood of an HLA-DRB1\*0405-positive healthy volunteer in a manner similar to Example 4, seeded in well of 96-well plate, and cocultured with E04.1 cells ( $1 \times 10^4$  cells). Growth response of E04.1 cells was then measured in a manner similar to Example 1. The results are shown in Fig. 8. E04.1 cells showed proliferative response when cocultured with dendritic cells pulsed with apoptosis-induced B-LCL (+) cells, but did not when cocultured with dendritic cells pulsed with apoptosis-induced B-LCL (-) cells. These results indicate that WT1<sub>332-347</sub> peptide is first generated through the degradation of WT1 protein in B-LCL (+) cells, then presented to HLA-DRB1\*0405 and induce proliferation of E04.1 cells.

Induction of apoptosis in B-LCL (-) and B-LCL (+) cells was conducted by osmotic shock. Namely,  $1 \times 10^6$  cells were suspended in 500  $\mu$ l of a hyperosmotic medium (RPMI medium containing 0.5 M sucrose, 10% w/v polyethylene glycol 1000 and 10 mM HEPES, pH 7.2), and left to stand at 37°C for 10 minutes. The culture was then diluted by 30-times with a hypoosmotic medium (60% RPMI, 40% water) previously adjusted to 37°C, and left to stand at 37 °C for 2 - 3 minutes. Cells were collected by centrifuging at room temperature for 5 minutes and used as apoptosis-induced cells. Induction of apoptosis was confirmed by a fluorescent dye for staining dead cells (Propidium Iodide, and AnnexinV, i.e., a

phosphatidyl serine-binding reagent).

**Example 8**

**Activation of E04.1 Cells with WT<sub>1332-347</sub> Peptide**

Dendritic cells prepared from blood of an HLA-DRB1\*0405-positive healthy volunteer in a manner similar to Example 4 were pulsed with WT<sub>1332-347</sub> peptide, mixed with E04.1 cells, and cultured for 24 hours. As a negative control group, dendritic cells not pulsed with the peptide were mixed with E04.1 cells. After 24-hour-cultivation, Brefeldin A was added to a final concentration of 10 μg/ml to inhibit exocytosis of E04.1 cells. Further, CD4-positive T cells were recovered after culturing for another 6 hours, and fixed with PBC containing 2% formaldehyde, and treated by permeabilization solution containing 0.1% saponin to increase the cell membrane permeability of antibody. The treated cells were then intracellularly stained by treating with PE-labeled anti-IFN-γ antibody (BD PharMingen) and FITC-labeled anti-IL-4 antibody (BD PharMingen), and analyzed using a flow cytometer. The results are shown in Fig. 9. It was revealed that E04.1 cells, when cocultured with dendritic cells pulsed with WT<sub>1332-347</sub> peptide, were induced strongly to produce IFN-γ which is a Th-1-type cytokine, but not to produce IL-4 which is a Th-2-type cytokine.

Unstimulated E04.1 cells were stained by treating with anti-CD4 antibody and anti-CXCR3 antibody, and analyzed by flow cytometer. The results are shown in Fig. 10. It was revealed that more than 90 % of E04.1 cells are CD4-positive T cells of Th-1 type which are positive for CD4 and CXCR3. CXCR3 is known to be a chemokine receptor highly expressed on Th-1 type immunocytes.

The above results indicate that WT<sub>1332-347</sub> peptide activate E04.1 cells, WT<sub>1332-347</sub>-specific CD4-positive cell line, and induce the cells to produce IFN-γ which is a Th-1 type cytokine. These results demonstrate that WT<sub>1332-347</sub> peptide activates and makes CD4-positive T cells differentiate into Th-1 type.

**Example 9****Enhancement of Induction and Activation of WT1-specific CTLs by WT1<sub>332-347</sub> Peptide**

PBMCs were prepared using blood of the same healthy volunteer (HLA-A\*2402/1101, DRB1\*0405/0803) as that used for establishment of E04.1 cells in a manner similar to Example 4, and seeded in 24-well culture plate at  $3 \times 10^4$  cells/well. To the well were added WT1<sub>235-243</sub> peptide (SEQ ID NO: 27) and E04.1 cells in the following manners, and the plate was cultured at 37°C for 7 days. WT1<sub>235-243</sub> peptide (20  $\mu$ g/ml); WT1<sub>235-243</sub> peptide (20  $\mu$ g/ml) + WT1<sub>332-347</sub> peptide (20  $\mu$ g/ml); WT1<sub>235-243</sub> peptide (20  $\mu$ g/ml) + E04.1 cells ( $1.5 \times 10^6$  cells/well); or WT1<sub>235-243</sub> peptide (20  $\mu$ g/ml) + WT1<sub>332-347</sub> peptide (20  $\mu$ g/ml) + E04.1 cells ( $1.5 \times 10^6$  cells/well). As medium, X-VIVO 15™ medium containing 10% AB serum was used. WT1<sub>235-243</sub> peptide used here is a cancer antigen peptide having activity of inducing HLA-A\*2402-restricted CTLs (WO2004/024175).

After 7-day-cultivation, cells were recovered and one half of the cells were stained using anti-CD8 antibody (BD PharMingen) and WT1<sub>235-243</sub> peptide/HLA-A\*2402-specific PE-labeled tetramer, and analyzed by flow cytometer. The results are shown in Fig. 11 (A-D). It has been reported that stimulation of PBMCs with WT1<sub>235-243</sub> peptide leads to induction of WT1<sub>235-243</sub> peptide-specific CTL precursors positive for both CD8 and WT1<sub>235-243</sub> peptide/HLA-A\*2402 (*Cancer Immunol Immunother*, 51, p614-620 (2002)). When PBMCs were stimulated with WT1<sub>235-243</sub> peptide alone, the percentage of WT1<sub>235-243</sub> peptide-specific CTL precursors was 0.12% (Fig. 11-A). When stimulation was conducted using WT1<sub>235-243</sub> peptide plus WT1<sub>332-347</sub> peptide, the percentage of WT1<sub>235-243</sub> peptide-specific CTL precursors increased to 0.69% (Fig. 11-B). When stimulation was conducted using WT1<sub>235-243</sub> peptide plus E04.1 cells, the percentage of WT1<sub>235-243</sub> peptide-specific CTL precursors further increased to 4.51% (Fig. 11-C). When stimulation was conducted using WT1<sub>235-243</sub> peptide plus

WT<sub>1</sub><sub>332-347</sub> peptide plus E04.1 cells, the percentage of WT<sub>1</sub><sub>235-243</sub> peptide-specific CTL precursors still further increased to 7.12% (Fig. 11-D).

Another half of the recovered cells ( $3 \times 10^5$  cells) were cocultured for 6 hours with dendritic cells pulsed with WT<sub>1</sub><sub>235-243</sub> peptide and undergone X-ray irradiation (30 Gy). One hour after the initiation of cultivation, Brefeldin A was added to inhibit exocytosis of cells. Cultivation was continued for another 5 hours and the cells were stained with anti-CD8 antibody and WT<sub>1</sub><sub>235-243</sub> peptide/HLA-A\*2402-specific PE-labeled tetramer. The cells were fixed and treated with a permeabilization solution to increase cell membrane permeability, and intracellularly stained by PE-labeled anti-IFN- $\gamma$  antibody in a manner similar to Example 8. As a negative control group, cells were stained with APC-labeled anti-mouse IgG antibody (BD PharMingen), and cell populations positive for both IFN- $\gamma$  and mouse IgG were excluded as non-specific staining.

The results are shown in Fig. 12 (A-D). When WT<sub>1</sub><sub>235-243</sub> peptide-specific CTL precursors are stimulated with WT<sub>1</sub><sub>235-243</sub> peptide for 6 hours, CTLs which are specific for activated WT<sub>1</sub><sub>235-243</sub> peptide and are positive for CD8, WT<sub>1</sub><sub>235-243</sub> peptide/HLA-A\*2402 and IFN- $\gamma$  are induced. When stimulation was conducted using WT<sub>1</sub><sub>235-243</sub> peptide alone, the percentage of CTLs specific for activated WT<sub>1</sub><sub>235-243</sub> peptide was 17.0% (Fig. 12-A). When stimulation was conducted using WT<sub>1</sub><sub>235-243</sub> peptide plus WT<sub>1</sub><sub>332-347</sub> peptide, the percentage of CTLs specific for activated WT<sub>1</sub><sub>235-243</sub> peptide was increased to 23.3% (Fig. 12-B). When stimulation was conducted using WT<sub>1</sub><sub>235-243</sub> peptide plus E04.1 cells, the percentage of CTLs specific for activated WT<sub>1</sub><sub>235-243</sub> peptide was increased to 25.7% (Fig. 12-C). When stimulation was conducted using WT<sub>1</sub><sub>235-243</sub> peptide plus WT<sub>1</sub><sub>332-347</sub> peptide plus E04.1 cells, the percentage of CTLs specific for activated WT<sub>1</sub><sub>235-243</sub> peptide was increased to 39.0% (Fig. 12-D).

From the above results, it was revealed that WT<sub>1</sub><sub>332-347</sub> peptide is a helper peptide which enhances the induction and activation of WT<sub>1</sub>-

specific CTL precursors. It was also revealed that E04.1 cell is a helper T cell which enhances the activation of WT1-specific CTLs and that its helper function is increased by WT1<sub>332-347</sub> peptide and the activation of WT1-specific CTLs is enhanced.

5      Example 10

Investigation into Promiscuous Nature of WT1<sub>332-347</sub> peptide

WT1<sub>332-347</sub> peptide was examined whether it also can bind to HLA-DRB1\*1502 molecule, which is said that many Japanese possess, and induce WT1<sub>332-347</sub>-specific CD4-positive T cells as a promiscuous helper peptide.

10     1.    Experimental Method

11     1)   Preparation of Dendritic Cells (DC)

Peripheral blood mononuclear cells (PBMCs) were isolated from peripheral blood of a healthy volunteer (HLA-DRB1\*1502/1403), and seeded in 6-well plastic plate using 1% AB-type serum (Nabi, Miami, FL) and X-VIVO15™ medium (Cambrex) at 1x10<sup>7</sup> cells/well, and cultured for 2 hours. After removing non-adherent cells, the remaining adherent cells were cultured in a medium containing 1000 IU/ml IL-4(PeproTech), 1000 IU/ml GM-CSF (PeproTech), 1%AB-type serum, and X-VIVO 15™ medium.

15     On days 2 and 4, medium was changed and IL-4 and GM-CSF were added, and on day 6, TNF- $\alpha$  was added up to 100 IU/ml to make dendritic cells mature.

20     2)   Induction of WT1<sub>332-347</sub>-specific CD4-positive T Cells

CD4-positive T cells were isolated from blood of the same volunteer using RosetteSep (StemCell) for separating CD4-positive T cells. The resulting CD4-positive T cells were seeded in 24-well plate at 3x10<sup>6</sup> cells/well, and stimulated with autologous dendritic cells (3x10<sup>5</sup> cells) pulsed with WT1<sub>332-347</sub> peptide (20  $\mu$ g/ml) and undergone radiation irradiation (25Gy). On the next day from stimulation, IL-2 was added up to 20 IU/ml. In a similar manner, the stimulated CD4-positive T cells were

stimulated every one week with dendritic cells pulsed with WT<sub>1332-347</sub> peptide (20  $\mu$ g/ml). Further, medium change was conducted using IL-2-containing medium on every other day following the second stimulation. In the experiments, CD4-positive T cells induced by 3 times of stimulation in total.

5           3)     Growth Assay

Growth assay was conducted by [<sup>3</sup>H]-thymidine incorporation method. CD4-positive T cells induced by stimulation with a peptide (3x10<sup>4</sup> cells; responder) were cocultured with PBMCs pulsed with a peptide selected from WT<sub>1332-347</sub>, WT<sub>1172-186</sub> and WT<sub>1225-243</sub> peptides and undergone radiation irradiation (1x10<sup>5</sup> cells, "stimulator") in a 96-well plate. As a negative control, DC(-) not pulsed with a peptide was used. After 80-hour-cocultivation, [<sup>3</sup>H]-thymidine (Amersham Biosciences) was added at 37kBq/well. The plate was incubated for another 16 hours and measured with  $\beta$  scintillation counter. Measurement unit is "count per minute(cpm)", and every assay was carried out in triplicate.

10           4)     Analysis of Cytokine Production by Flow Cytometry

In the same manner as growth assay, CD4-positive T cells were cocultured with stimulators for 2 hours, and thereto was added Brefeldin A. Four hours later, cells were recovered, subjected to treatment for fixation and permeation, stained with FITC-labeled anti-IL-4 antibody (BD Pharmingen) and PE-labeled anti-IFN- $\gamma$  antibody (BD Pharmingen), and analyzed by flow cytometry.

15           5)     ELISA Assay

PBMCs (6x10<sup>5</sup> cells) pulsed or not pulsed with WT<sub>1332-347</sub> peptide were treated by radiation irradiation (25Gy), and each group of cells was cocultured with WT<sub>1332-347</sub>-induced CD4-positive T cells (6x10<sup>5</sup> cells). After 72-hour-cultivation, the supernatant was recovered, and 300  $\mu$ l of the solution was used for measurement of IL-4 and IFN- $\gamma$ .

20           6)     TCR Repertoire Assay

Repertoire of  $\beta$  chain of T-cell receptor (TCR) for CD4-positive T cells induced by WT<sub>1332-347</sub> peptide was analyzed using TCR V $\beta$  repertoire Kit (BECKMAN COULTER), FACsort (BECTON DICKINSON).

## 2. Experimental Results

CD4-positive T cells isolated from blood of an healthy volunteer (HLA-DRB1\*1502/1403) were stimulated three times in total with autologous dendritic cells pulsed with WT<sub>1332-347</sub> peptide. The so induced CD4-positive T cells were examined for the peptide specificity by growth assay using each of WT<sub>1172-186</sub>, WT<sub>1225-243</sub> and WT<sub>1332-347</sub> peptides. As a result, CD4-positive T cells induced by WT<sub>1332-347</sub> peptide did not proliferate in the absence of the peptide or under the stimulation with WT<sub>1172-186</sub> or WT<sub>1225-243</sub>, but proliferated to become about 10-times as much when stimulated with WT<sub>1332-347</sub> (Fig. 13). From these results, the induced CD4-positive T cells have specificity for WT<sub>1332-347</sub>.

The WT<sub>1332-347</sub> peptide-induced CD4-positive T cells were subjected to TCR repertoire assay. The results are shown in Fig. 14. Cells having V $\beta$  3 and those having V $\beta$  20 were dominant and each accounted for 10% of the total.

These dominant CD4-positive T cells were separated by sorting and the cell line having V $\beta$  3 was named as E15.1 subline, while the one having V $\beta$  20 as E15.2 subline. Of these two cell lines, E15.2 subline showed higher responsiveness to WT<sub>1332-347</sub> peptide (Fig. 15).

E15.2 subline was then stimulated with WT<sub>1332-347</sub> peptide, and the secreted IL-4 and IFN- $\gamma$  were measured by Intracellular stain method. As a result, it was revealed that IFN- $\gamma$  (Th-1-type cytokine) and not IL-4 (Th-2-type cytokine) is dominantly produced by said cell line (Fig. 16). It was also revealed that the WT<sub>1332-347</sub>-specific proliferative-response of E15.2 subline depends on the concentration of WT<sub>1332-347</sub> (Fig. 17). These results indicated that E15.2 subline is a Th-1-type CD4-positive T cell line specific for WT<sub>1332-347</sub>.

As mentioned above, it was possible to induce Th-1-type CD4-positive T cell lines specific for WT<sub>1332-347</sub> from CD4-positive T cells derived from a healthy volunteer who is positive for HLA-DRB1\*1502 molecule but negative for HLA-DRB1\*0405 molecule. Based on these results, it is considered that said CD4-positive T cells participate in cellular immunity and can activate CTLs through the secretion of cytokines. Thus, it was shown that antitumor effects can be further enhanced by using WT<sub>1332-347</sub> in combination with HLA-class I-restricted WT1 peptide (cancer antigen peptide) capable of activating CTLs.

PBMCs derived from an HLA-DRB1\*1502-positive healthy volunteer (1502/0901) or an HLA-DRB1\*1502-negative healthy volunteer (1302/0803) were pulsed with WT<sub>1332-347</sub> peptide to obtain stimulators. Each of stimulators was cocultured with E15.2 subline, and analyzed for WT<sub>1332-347</sub>-specific proliferation by growth assay. The results are shown in Fig. 18. In an HLA-DRB1\*1502-positive healthy volunteer, WT<sub>1332-347</sub>-specific proliferation was observed but in an HLA-DRB1\*1502-negative healthy volunteer, no proliferation was observed (Fig. 18). This indicated that the WT<sub>1332-347</sub>-specific proliferation of E15.2 subline is restricted to HLA-DRB1\*1502.

As described above, analysis conducted using E15.2 subline which is a Th-1-type CD4-positive T cell line specific for WT<sub>1332-347</sub> peptide demonstrated that WT<sub>1332-347</sub> is a promiscuous helper peptide which binds not only to HLA-DRB1\*0405 molecule but also to HLA-DRB1\*1502 molecule which molecules are found in the first and the third frequencies, respectively, among Japanese.

#### INDUSTRIAL APPLICABILITY OF THE INVENTION

The present invention provides a WT1-derived HLA-DRB1\*0405-binding antigen peptide, a polynucleotide encoding said peptide, a helper T cell inducer comprising said peptide or polynucleotide, and the like. The

helper T cell inducer of the present invention is useful as an enhancer of cancer vaccine efficacy. The enhancer of cancer vaccine efficacy of the present invention is applicable to many cancer patients positive for HLA-DRB1\*0405, and particularly useful as an enhancer of WT1 vaccine efficacy.